EMERGENCE AND SURVIVAL OF LAKE TROUT (Salvelinus namaycush) AND BROOK TROUT (S. fontinalis) FROM ARTIFICIAL SUBSTRATES IN AN ACID LAKE

J.M.Gunn and W.Keller

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EMERGENCE AND SURVIVAL OF LAKE TROUT *(Salvelinus namaycush)* AND BROOK TROUT *(S. fontinalis)* FROM ARTIFICIAL SUBSTRATES IN AN ACID LAKE

J. M. Gunn
Ontario Ministry of Natural Resources
Sudbury, Ontario. P3A 4S2

W. Keller
Ontario Ministry of the Environment
Sudbury, Ontario. P3E 5P9

Ministry of
Natural
Resources

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Eyed eggs of lake trout *(Salvelinus namaycush)* and brook trout *(S. fontinalis)* were incubated overwinter in crushed limestone and mixed noncalcareous gravel substrates in the acidic waters (pH ∿ 5.2) of George Lake. Alevin emergence for both species (33.6-73.0%) was generally good from limestone substrates (interstitial water pH > 6) and almost nonexistent (0.1-1.3%) from mixed gravel substrates (interstitial water pH ∿ 5.5).

Survival of alevins of both species hatched in limestone was high during 7-d holding periods in both the acidic lake (70.0-100.0%) and at a control site in the near-neutral waters of Killarney Bay (89.5-100%). High alevin mortality observed after 30 d of an extended (41-d) exposure in George Lake appeared related to feeding and containment problems rather than pH toxicity.

The substantial alevin emergence from limestone and the high survival during 7-d and 30-d holding periods indicate that small scale limestone applications to provide spawning substrates would enhance salmonid recruitment in some acidic lakes.

Key words: lake trout, brook trout, pH, acidic lake, limestone, spawning substrate.

EMERGENCE AND SURVIVAL OF LAKE TROUT *(Salvelinus namaycush)* AND BROOK TROUT *(S. fontinalis)* FROM ARTIFICIAL SUBSTRATES IN AN ACID LAKE

INTRODUCTION

The detrimental effects of low pH on the early developmental stages of fish have been studied extensively under laboratory conditions by Craig and Baksi (1977), Daye and Garside (1977), Johansson et al. (1977), and others. The effects of low pH are known to be highly variable under natural conditions (Fromm 1980), presumably through interactions with other factors such as oxygen (Wiebe et al. 1934; Townsend and Cheyne 1944), carbon dioxide (Lloyd and Jordan 1964; Janssen and Randall 1975), temperature (Kwain 1975) and metal concentrations (Chakoumakos et al. 1979; Driscoll et al. 1980), but the need for field testing of fish responses in acidic environments is obvious.

In the present study, we have concentrated on the effects of low pH waters on the early stages of lake trout *(Salvelinus namaycush)* and brook trout *(S. fontinalis)*. Experiments were carried out in George Lake (46°08'N, 81°24'W) an acidic lake 56 km southwest of Sudbury, Ontario. Detailed physical and chemical data for this lake and the history of its deteriorating fishery have been previously reported (Beamish 1974; Beamish et al. 1975). Lake trout received some added emphasis during our study since they are indigenous to the study lake and little information is available on the pH sensitivity of this highly prized sportfish.

MATERIALS AND METHODS

PRELIMINARY NETTING:

George Lake was netted during October 9 - 12, 1979 (surface temperature 12°C) to assess the lake trout population and to examine the condition of reproductive organs, particularly ovaries. Three gangs (76.3, 91.5, and 122.0 m) of monofilament gillnet (2.5-12.6 cm square mesh) were used, with a total netting effort of 167 hours at 8 sites.

OVERWINTER INCUBATION:

The incubators (60 x 60 x 30 cm frame and screen hatching boxes) used in this experiment have been described previously (Gunn and Keller 1980). Ten incubators, with emergence traps (Collins 1975) attached, were set on a sand bottom in depths of 3.4-4.9 m near the outlet of George Lake.

Six incubators (3 filled with ∿ 5-cm-diameter crushed limestone; 3 filled with ∿ 5-cm-diameter mixed noncalcareous gravel) contained lake trout eggs (318 in each) and 4 (2 limestone; 2 mixed gravel) contained brook trout eggs (954 in each). Eggs of both species were eyed when planted. Lake trout eggs ($\bar{x}$ diameter 5.8 mm; $\bar{x}$ dry weight 0.0304 g) were obtained from Lake Manitou (45°45'N, 82°00'W) native stock, hardened in Lake Manitou water (pH 8.1, alkalinity 115 mg/L), raised to the eyed stage at the Sandfield hatchery and planted in George Lake on November 27, 1979 (surface temperature 4°C). Brook trout eggs ($\bar{x}$ diameter 4.6 mm; $\bar{x}$ dry weight 0.0177 g) obtained from the domestic stock at Hills Lake hatchery (47°60'N, 79°80'W) were hardened and raised in Hills Lake hatchery water (pH 7.8, alkalinity ∿ 100 mg/L) and planted on November 28.

Additional egg containers (Whitlock Vibert Boxes) were buried ∿ 20 cm deep in substrate within perforated plastic pails (9.0-L) which were placed at a 3 m depth in George Lake (lake trout - 1 limestone, 1 mixed gravel; brook trout - 3 limestone, 3 mixed gravel) near the incubator site. The eggs in the pails were examined by SCUBA divers to predict emergence time from the incubators.

The pails were retrieved from under ice on March 18, 1980 and dead eggs (white, opaque) and live fry were examined and counted. Weekly dives on the incubators began April 1, 1980. When fry began appearing in the collection bottles, 3 dives per week were scheduled. On each collection, the bottles were brought to surface and the fry were counted, then transferred directly into well aerated water from the holding sites.

HOLDING OF ALEVINS:

Alevins were held for 7 d in screened, 1.5 mm perforated 22.5-L plastic pails (tops covered with black plastic) to determine short-term survival. Four lots each (alevin $\underline{n}$ = 17-50) of lake trout and brook trout were held at a shoreline area (near outlet) in George Lake and in Killarney Bay, on Georgian Bay ∿ 12 km from George Lake. Alevins were examined and fed dry formulated trout food *ad libitum* three times per day. All dead alevins were removed daily and at the end of the holding period live alevins were removed and frozen for subsequent weighing. Weights were determined after drying at 65°C for 24 h to constant weight.

Two lots (1 lake trout; 1 brook trout) were maintained at the George Lake holding site for 41 d to examine longer-term survival.

Subsamples of alevins from the holding pens were preserved in 70% ethanol for stomach contents examination.

WATER SAMPLING:

To permit investigation of chemical conditions within the substrates, two incubators (1 limestone filled; 1 mixed gravel filled) equipped with water sampling tubes (Gunn and Keller 1980) were set in shallow (0.5 m) water. Between November 28 and December 15, 1979 (sampling terminated with freeze-up) four samples of interstitial water were drawn (by vacuum) through 4.0 mm I.D. plastic tubing into a well rinsed (distilled and lake water) 2.0-L glass flask. Aliquots for analyses were dispensed from the flask into clean, rinsed containers (500-mL polystyrene for pH, total inflection point (TIP) alkalinity and conductivity; 500-mL acid-washed polyethylene for trace metals; 1.0-L glass for major ions).

At monthly intervals during ice-cover, water samples were collected from surface, 3 m and 6 m with a 2.0-L Van Dorn bottle and dissolved oxygen and temperature profiles (YSI model 54 meter) were measured near the submerged incubators. Daily sampling (surface grab samples) at the alevin holding sites was conducted from April 10 - June 3, 1980.

Conductivity, TIP alkalinity and pH determinations were conducted either in the field or within a few hours of collection. Analyses of major ion and total trace metal (unfiltered HNO_3 added in the field) concentrations were performed at the Ministry of the Environment laboratories in Toronto (MOE 1975).

RESULTS

STUDY LAKE FISH COMMUNITY:

Test netting produced only 2 lake trout (1 male, 1 female). Both the male (total length (T.L.) 64.6 cm; weight 2.40 kg) and female (T.L. 71.2 cm; weight 4.15 kg) were sexually mature but their gonads were not fully ripe. The ovary of the female was in the active stage, stage 5 according to the scheme of Vladykov (1956). Both egg size ($\bar{x}$ diameter 4.6 mm) and fecundity (1105/kg body weight) were low but still within observed ranges for reproducing populations (Martin and Olver 1980). Other species captured during the October 9 - 12 netting were 112 yellow perch *(Perca flavescens)*, 35 rock bass *(Ambloplites rupestris)*, 26 white sucker *(Catostomus commersoni)*, 12 lake herring *(Coregonus artedii)*, 5 brown bullhead *(Ictalurus nebulosus)*, 1 pumpkinseed *(Lepomis gibbosus)*, and 1 northern pike *(Esox lucius)*.

OVERWINTER INCUBATION AND SPRINGTIME EMERGENCE

Within limestone, substantial elevations in pH TIP alkalinity and conductivity occurred in comparison to ambient George Lake water and the interstitial water of mixed gravel (Table 1). Concentrations of trace metals were generally similar between substrates and the ambient lake water. However, there was evidence of slight Zn and Fe contamination associated with the metal screening of the incubators. Under ice cover (January 9 - April 21) ambient conditions near the submerged incubators were: pH 5.03-5.21; temperature 2.0-2.2°C; dissolved oxygen 12.6-13.4 mg/L.

Examination of eggs and sac fry in the plastic pails on March 18 showed that yolk absorption was well advanced in both lake trout and brook trout incubated in limestone (Fig. 1A). Although some fry may have escaped from the pails, the effect of substrate differences on survival was dramatic. Only one live lake trout fry (0.4%) was found in mixed gravel while a total of 604 (59.9%) brook trout and 130 (59.6%) lake trout were alive in limestone. Some dead eggs and fry had decomposed, but almost all of the brook trout eggs in mixed gravel appeared to have died in the eyed stage while the lake trout appeared to have died during hatching (Fig. 2). Many of the dead lake trout sac fry were still partially enclosed in the egg capsule.

Table 1. Chemistry of ambient George Lake water and the interstitial waters of limestone and noncalcareous gravel substrates, November 28 - December 15, 1979.

	Limestone		Mixed Gravel		Ambient lake	
	$\bar{x}$ ± SD	n	$\bar{x}$ ± SD	n	$\bar{x}$ ± SD	n
pH	6.29 ± 0.14	4	5.45 ± 0.13	4	5.24 ± 0.12	4
Conductivity (µS/cm)	39.5 ± 1.9	4	37.3 ± 0.5	4	36.8 ± 1.0	4
TIP alkalinity (mg/L as $CaCO_3$)	2.00 ± 0.95	4	0.09 ± 0.14	4	0.00	4
Total Cu (µg/L)	5 ± 3	4	4 ± 2	3	4 ± 4	4
Total Ni (µg/L)	6 ± 1	4	6 ± 3	3	8 ± 2	4
Total Zn (µg/L)	29 ± 16	4	29 ± 7	3	18 ± 6	4
Total Al (µg/L)	178 ± 66	4	167 ± 29	3	130 ± 14	4
Total Mn (µg/L)	115 ± 10	4	123 ± 6	3	128 ± 10	4
Total Fe (µg/L)	99 ± 67	4	103 ± 55	3	32 ± 18	4

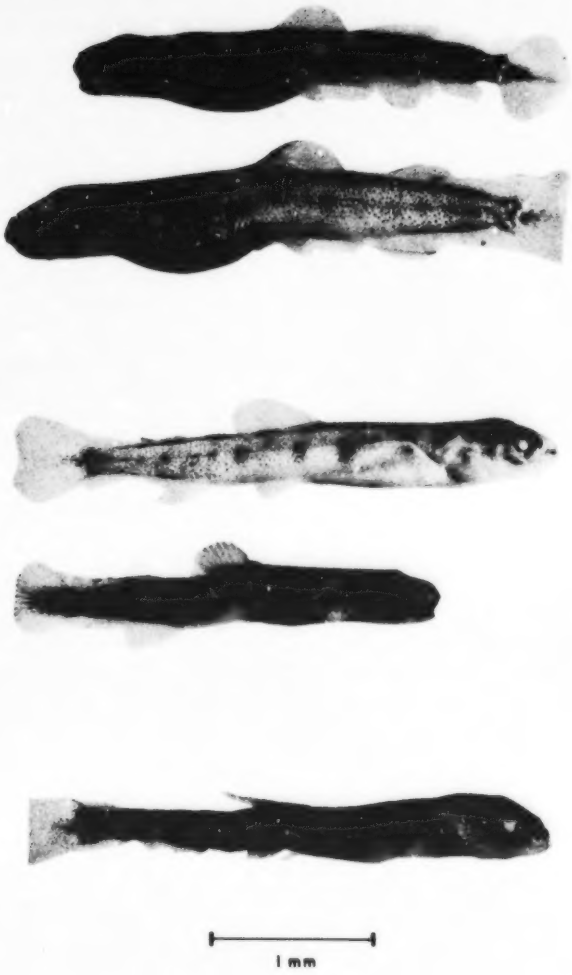

Fig. 1. A) Brook trout (top) and lake trout (bottom) sac fry from limestone substrates, March 18, 1980.
B) Emergent lake trout (top) and brook trout (bottom) alevins from limestone substrates, May 7, 1980.
C) Emaciated lake trout alevin after holding period (April 21 - May 25, 1980) in George Lake.

Emergence from the incubators began under ice cover. The first alevins of both species (Fig. 1B) were observed on April 18 (lake trout, 186-189 days post fertilization; brook trout, 189 days post fertilization). Emergence peaked April 25-30 (Fig. 3). With few exceptions, emergence occurred only from limestone. Totals of 232 (73.0%), 171 (53.8%) and 230 (72.3%) lake trout alevins emerged from limestone while only 1 (0.3%), 4 (1.3%) and 2 (0.6%) alevins survived to emerge from mixed gravel. Only 1 (0.1%) brook trout alevin emerged from the two mixed gravel filled incubators while 340 (33.6%) and 650 (64.3%) brook trout alevins emerged from limestone. The limited emergence of both species that did occur from mixed gravel began 17 d after the start of emergence from the limestone (Fig. 3).

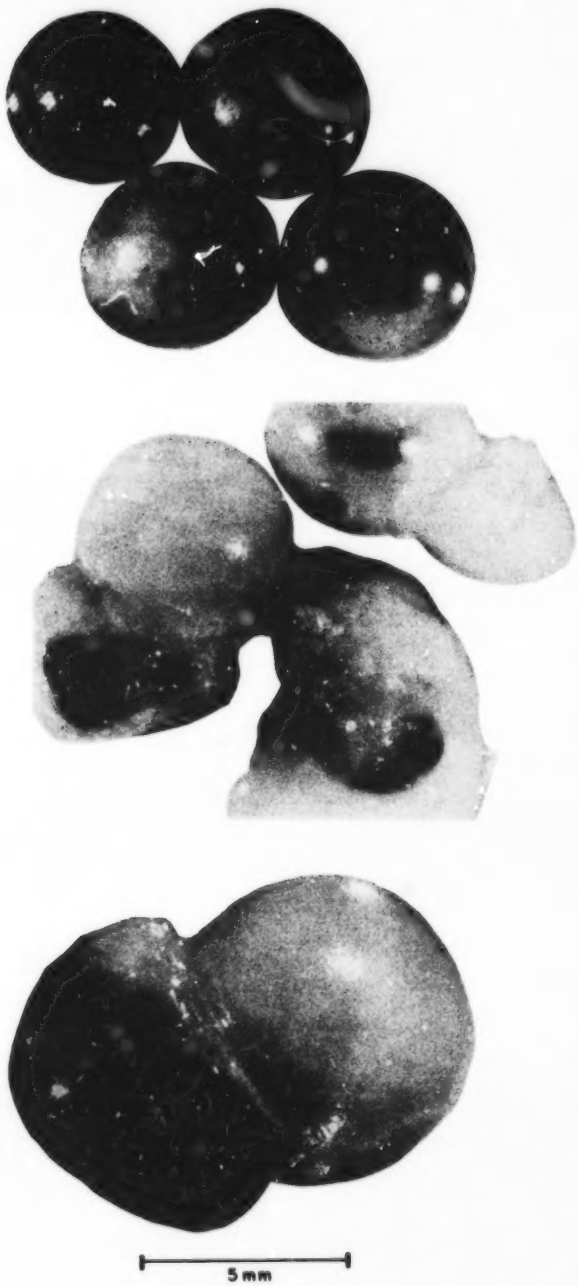

Fig. 2. Trout eggs from mixed gravel substrates in George Lake, March 18, 1980.
A) Dead, eyed brook trout eggs.
B) and C) Dead, partially hatched lake trout.

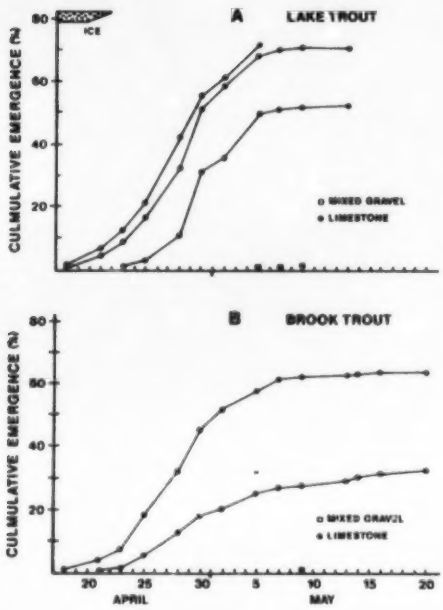

Fig. 3. Emergence of A) lake trout, and B) brook trout from artificial substrates in George Lake. Cumulative emergence (%) from individual incubators is shown. Original egg numbers/incubator were: lake trout - 318; brook trout - - 954.

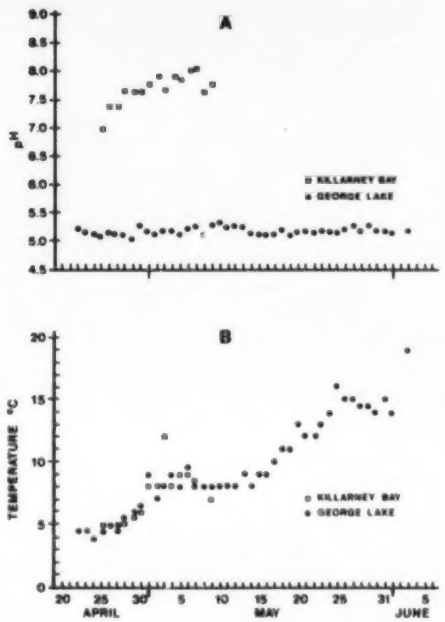

Fig. 4. Temporal variation in A) pH, and B) temperature at the holding sites in George Lake and Killarney Bay.

Table 2. Chemistry of holding areas in George Lake (April 22 - June 3, 1980) and Killarney Bay (April 25 - May 9, 1980).

	George Lake		Killarney Bay	
	$\bar{x}$ ± SD	n	$\bar{x}$ ± SD	n
pH	5.21 ± 0.06	42	7.61 ± 0.27	15
Conductivity (µS/cm)	36.2 ± 1.0	6	180.0 ± 7.1	2
Ca (mg/L)	2.8 ± 0.4	6	22.0 ± 1.4	2
Mg (mg/L)	0.83 ± 0.21	6	5.0 ± 0.0	2
Na (mg/L)	1.0 ± 0.2	6	2.9 ± 0.2	2
K (mg/L)	0.53 ± 0.26	6	1.03 ± 0.18	2
SO_4 (mg/L)	10.9 ± 0.6	6	14.8 ± 0.3	2
Cl (mg/L)	0.54 ± 0.06	6	4.68 ± 0.04	2
NO_3 (mg/L)	0.123 ± 0.043	6	0.158 ± 0.065	2
Total Cu (µg/L)	3 ± 2	6	3 ± 1	3
Total Ni (µg/L)	7 ± 2	6	4 ± 0	3
Total Zn (µg/L)	20 ± 1	6	3 ± 1	3
Total Al (µg/L)	222 ± 34	6	60 ± 15	3
Total Mn (µg/L)	237 ± 222	6	6 ± 2	3
Total Fe (µg/L)	107 ± 45	6	79 ± 35	3

ALEVIN SURVIVAL, SIZE AND FEEDING

Marked chemical differences existed (Table 2; Fig. 4) between the two holding sites used during the short-term (7-d) survival experiments (April 25 - May 9). The respective average pH values of George Lake and Killarney Bay were 5.21 and 7.61. In addition, Killarney Bay exhibited substantially higher concentrations of major ions and lower concentrations of most trace metals, particularly Mn, Al and Zn, than George Lake (Table 2). Temperatures increased steadily (5-11°C) at both sites (Fig. 4). Dissolved oxygen remained near saturation.

Some variability between alevin lots was observed, but generally 7-d survival was higher for alevins of both species held in Killarney Bay (Table 3). Differences between sites, however, were not statistically significant.

Brook trout from Killarney Bay were significantly (t-test; $P \leq 0.05$) larger after 7 d than those held in George Lake. Lake trout also appeared larger at Killarney Bay, but the differences were not statistically significant (Table 4).

Alevins at both sites showed little apparent interest in the formulated food. The stomachs of many alevins were completely empty. Inspection also revealed a greater variety of natural food items in both species from Killarney Bay (Table 5). Ostracods were common in the stomachs of Killarney Bay alevins (one contained > 50) although they were absent from the diet of George Lake alevins and did not appear in dredge and tow net collections from George Lake holding area (Keller unpublished data). Copepods also appeared only in the stomachs of Killarney Bay alevins. Diptera and Cladocera were included in the diet of alevins from both sites.

Despite the feeding problems encountered (i.e. little utilization of formulated food), brook trout and lake trout alevins appeared relatively hardy under the low pH conditions of George Lake. Minimal mortality occurred during the first 30 d of the extended holding experiment (Fig. 5), however, alevins were severely emaciated (Fig. 1C). Substantial mortality occurred only when water temperatures increased sharply.

DISCUSSION

The acidic conditions within noncalcareous mixed gravel proved lethal to the early developmental stages of lake trout and brook trout in George Lake. However, hydrogen ions may not be the primary toxicant. The form and quantity of dissolved metals, aluminum in particular, are controlled by pH (Dickson 1978; Schindler et al. 1980). Aluminum concentrations observed in our *in situ* study are similar to levels found toxic at high, although not directly physiologically damaging (H^+) (Muniz and Leivestad 1980). The direct or indirect role of pH on toxicity remains unresolved.

Table 3. Lake trout and brook trout alevin survival during holding periods (7-d) in George Lake (pH 5.05-5.30) and Killarney Bay pH (7.00-8.07).

Species	Site	Lot	Holding Period	Original Number	Final Number	Survival (%)
Lake Trout	Killarney Bay	KL-1	April 25-May 2	24	24	100.0
		KL-2	April 28-May 5	38	34	89.5
		KL-3	April 28-May 5	42	41	97.6
		KL-4	May 2-May 9	17	17	100.0
	George Lake	GL-1	April 25-May 2	26	23	88.5
		GL-2	April 28-May 5	43	31	72.1
		GL-3	April 30-May 7	33	33	100.0
		GL-4	May 2-May 9	20	14	70.0
Brook trout	Killarney Bay	KB-1	April 25-May 2	34	34	100.0
		KB-2	April 25-May 2	35	35	100.0
		KB-3	April 30-May 7	45	44	97.8
		KB-4	May 2-May 9	36	36	100.0
	George Lake	GB-1	April 25-May 2	37	35	94.6
		GB-2	April 28-May 5	50	46	92.0
		GB-3	April 30-May 7	54	54	100.0
		GB-4	May 2-May 9	19	18	94.3

Table 4. Comparative size of lake trout and brook trout alevins after 7-d holding periods in George Lake and Killarney Bay.

Species	Holding period	Killarney Bay Lot[a]	Killarney Bay dry weight (g) $\bar{x}$ ± SD	Killarney Bay n	George Lake Lot[a]	George Lake dry weight (g) $\bar{x}$ ± SD	George Lake n	Difference
Lake trout	April 25-May 2	KL-1	0.0182 ± .0039	24	GL-1	0.0175 ± .0042	23	ns
	May 2-May 9	KL-4	0.0190 ± .0031	17	GL-4	0.0170 ± .0032	14	ns
Brook trout	April 25-May 2	KB-1	0.0107 ± .0019	32	GB-1	0.0085 ± .0016	35	**
		KB-2	0.0096 ± .0022	35				
	May 2-May 9	KB-4	0.0119 ± .0019	33	GB-4	0.0079 ± .0012	18	**

ns - no significant difference

** - significant at $P \leq 0.05$

a - no weights available for additional lots indicated in Table 3. Samples spoiled during storage. Initial weight data also not available.

Table 5. Frequency of occurrence (%) of food items in stomachs of lake trout and brook trout alevins held in George Lake and Killarney Bay.

Stomach contents	Lake trout		Brook trout	
	George Lake (n = 15)	Killarney Bay (n = 10)	George Lake (n = 15)	Killarney Bay (n = 13)
Empty	53.3	20.0	13.3	15.4
Hatchery food	13.3	40.0	86.7[a]	15.4
Cladocera	20.0	20.0	6.7	7.7
Ostracoda		40.0		46.2
Copepoda		30.0		38.5
Insecta				
Ephemeroptera (larvae)		10.0		
Hemiptera (larvae)		10.0		
Diptera (larvae)	20			15.4
Diptera (pupae)		10.0	13.3	30.8

a often only trace amounts present

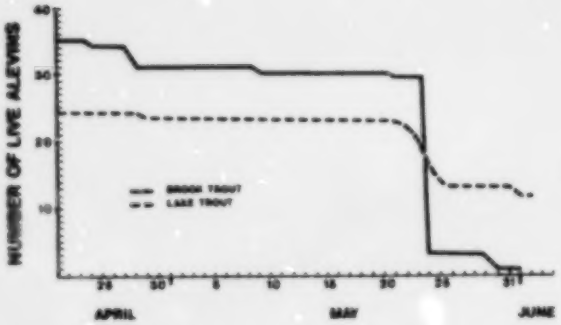

Fig. 5 Survival (41-d) of lake trout and brook trout alevins held in George Lake.

Hatching appeared to be a particularly critical period for the lake trout. Similar observations of high, pH-related mortality shortly after rupturing of the egg capsule have been reported for Atlantic salmon, *Salmo salar* (Daye and Garside 1977; Johannson et al. 1977), brown trout, *Salmo trutta* (Johannson et al. 1977) and brook trout (Menendez 1976). Histological studies by Runn et al (1977) indicated that the normal degeneration of egg capsules in perch *Perca fluviatilis* through enzyme action was disturbed at low pH. Runn et al. (1977) suggested that such a phenomenon could explain the inability of fry to free themselves from ruptured egg capsules. Peterson et al. (1980) have demonstrated delayed hatching of Atlantic salmon eggs exposed to water of lowered pH (4.0-5.5). Our observations on later initiation of emergence among the few alevins hatched in mixed gravel (17 d after commencement of emergence from limestone) support these findings.

The almost complete mortality of lake trout in mixed gravel substrates suggests that such a mechanism could have caused or contributed to the virtual extinction of lake trout in the study lake. However, a retrospective cause - effect analysis must be approached with care since other more subtle, but no less critical effects of low pH on fish reproduction including reductions in egg numbers (Mount 1973; Craig and Baksi 1977) egg size (Runn et al. 1977; Kennedy 1980), and viability (Smith 1977) have been documented. Beamish et al. (1975) found that white suckers, brown bullheads, pumpkinseeds, and northern pike failed to spawn in George Lake and suggested that altered calcium metabolism (as evidenced by low serum calcium concentrations) due to low pH may have caused the spawning failures. Kennedy (1980), working in an artificially acidified lake (pH 5.75), found that lake trout continued to spawn with a high fertilization rate (∿ 95%), but within 15 d after fertilization 59% of all fertilized eggs failed to reach gastrulation and of the surviving embryos, 60% displayed gross anatomical deformations. Obviously, additional information on the many aspects of reproductive impairment by low pH is required.

Brook trout are generally regarded as the most acid tolerant salmonid species (Grande et al. 1978) but the low pH (∿ 5.5) conditions within mixed gravel substrates proved lethal to all (eggs and sac fry) but a single individual in our experiment. Menendez (1976) reported similar findings for chronic exposure of brook trout to low pH. He found the hatchability of eggs to steadily decrease from 82% in the control situation (pH 7.04) to 26% at pH 5.09.

It should be noted that in our experiment eggs were hardened and raised to the eyed stage in high pH water before transfer to the study lake. Lee and Gerking (1980) have shown that eggs hardened in high pH water are more resistant when transferred to low pH solutions than are fresh fertilized eggs. Mortality may have been even more rapid had fresh fertilized eggs been used in this experiment.

Our observations on the timing of alevin (both brook trout and lake trout) emergence reinforce previous concerns (Hagen and Langeland 1973; Hultberg 1976; Jeffries et al. 1979) over the potentially drastic impact of acidic snowmelt episodes on fish populations. The beginning of emergence in George Lake (April 18) coincided with the period of maximum snowmelt, during which very dilute (conductivity 15 µS/cm) but highly acidic (pH 4.65) meltwater accumulated between the shoreline and receding ice cover to a depth of ∿ 2m. Lake trout often spawn in shoreline rubble at depths of 0.2-2m (Martin 1957; Scott and Crossman 1973), therefore, such a phenomenon (i.e. depression of surface or shoreline pH) could have a profound effect on recruitment, even in only marginally acidic lakes, since sac fry and emerging alevins would be subjected to conditions of maximum acidity. In lakes, brook trout generally spawn over spring upwellings, but inudations of meltwater may similarly affect eggs and fry. In tests of lake trout and brook trout sac fry survival in meltwater (pH 4.49; conductivity 18.3 µS/cm) Grande et al. (1978) found 100% lake trout mortality in a 3-d exposure and 100% brook trout mortality in 12-13 d exposure.

Qualitative and quantitative variations in natural food availability and its utilization make it impossible to attribute the observed size differences to pH. Reviews of the literature (EIFAC 1969; Fromm 1980) emphasize the contradictions and difficulties inherent in evaluating the isolated effects of pH on fish growth. Most of the bioenergetic aspects of low pH effects (especially metabolic demands imposed by low pH) remain unclear.

The high survival rates (70.0-100%) of alevins of both species held in acidic water, in combination with the good emergence (33.6-73.0%) from limestone, are encouraging. Although eventual (41-d) alevin mortality was substantial, deaths appeared directly related to feeding problems perhaps combined with rapid temperature increases, rather than low pH. Similar problems with starting alevins on formulated feed are often encountered in hatcheries (D. Storm, G. Clark personal communication). Under natural

conditions improved long-term survival could be reasonably expected. Based on the present and a previous experiment (Gunn and Keller 1980) there is potential for the use of small scale limestone treatments (such as artificial limestone spawning beds or modifications of our incubators) to maintain the fisheries of acidic lakes.

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POOR

QUALITY

ORIGINAL